Mountain Wave Momentum Fluxes in the Southern Hemisphere from Satellite Measurements

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Motivation

- Relatively lacking in mountainous terrain.

- Orographic gravity wave drag relatively inefficient in climate simulations.

- Special non-orographic gravity wave drag tuning parameters needed to prevent problems in chemistry-climate models:

    - Polar winter jet is too strong, and temperatures are too cold.

    - Breakdown of the vortex in spring is too late.

    - Too much ozone loss in spring.

Motivation

Sensitivity of Southern Hemisphere Temperatures and Ozone to parameterized gravity wave drag

Stress = Momentum Flux
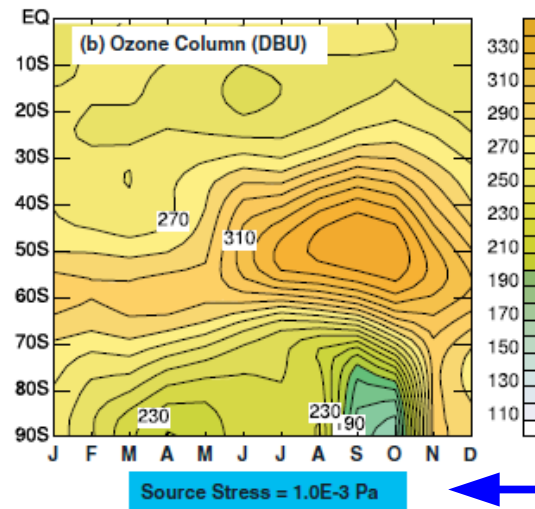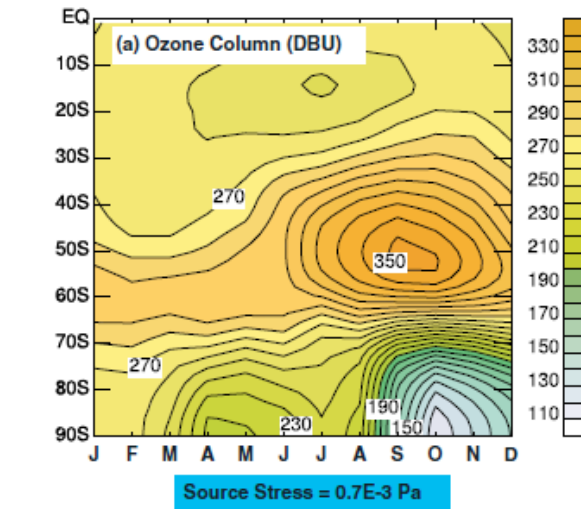
Overly strong stratospheric winds are coupled to excessively cold temperatures and excessive ozone depletion.
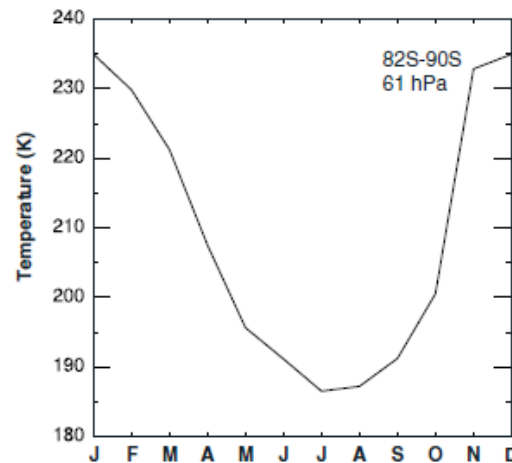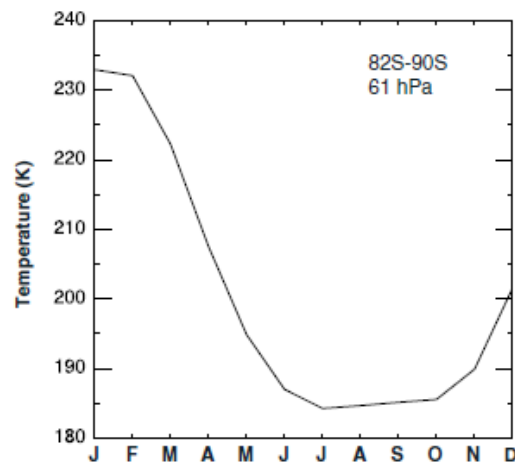
Small changes to parameterized wave drag can have large effects on the depth and duration of the ozone hole.

Alexander et al. [2010] – WACCM results from F. Sassi

Gravity wave effects on circulation

Momentum flux *(F$_M$)* is a key parameter:

$$\varepsilon \, dF_M / dz = -\rho \ _{\text{x}} \text{(Force on the Circulation)}$$

F_M is constant in the absence of dissipation/breaking

dF_M / dz depends on <u>local</u> wave amplitude and on
<u>local</u> wave properties, *e.g. k,m.* These determine
where the wave becomes unstable.

ε = a tuning parameter representing intermittency.

This is an oversimplification, but approximately describes current
gravity wave parameterizations in climate models.

Outline:

I. Using AIRS to estimate momentum flux for small-scale orographic waves in the Southern Hemisphere and evaluate their effects on the circulation.

II. Combining AIRS and HIRDLS to examine 3-dimensional details of a southern Andes mountain wave event and the relative importance of small versus larger-scale waves.

Southern Andes and downstream influence

South Georgia and the South Sandwich Islands

Kerguelen and Heard Islands

Orographic Waves over Islands in the Southern Ocean
AIRS Observations above South Georgia at 40 km

Brightness Temperature Fluctuations
A 4-day event in September 2003 [Alexander et al., 2009]
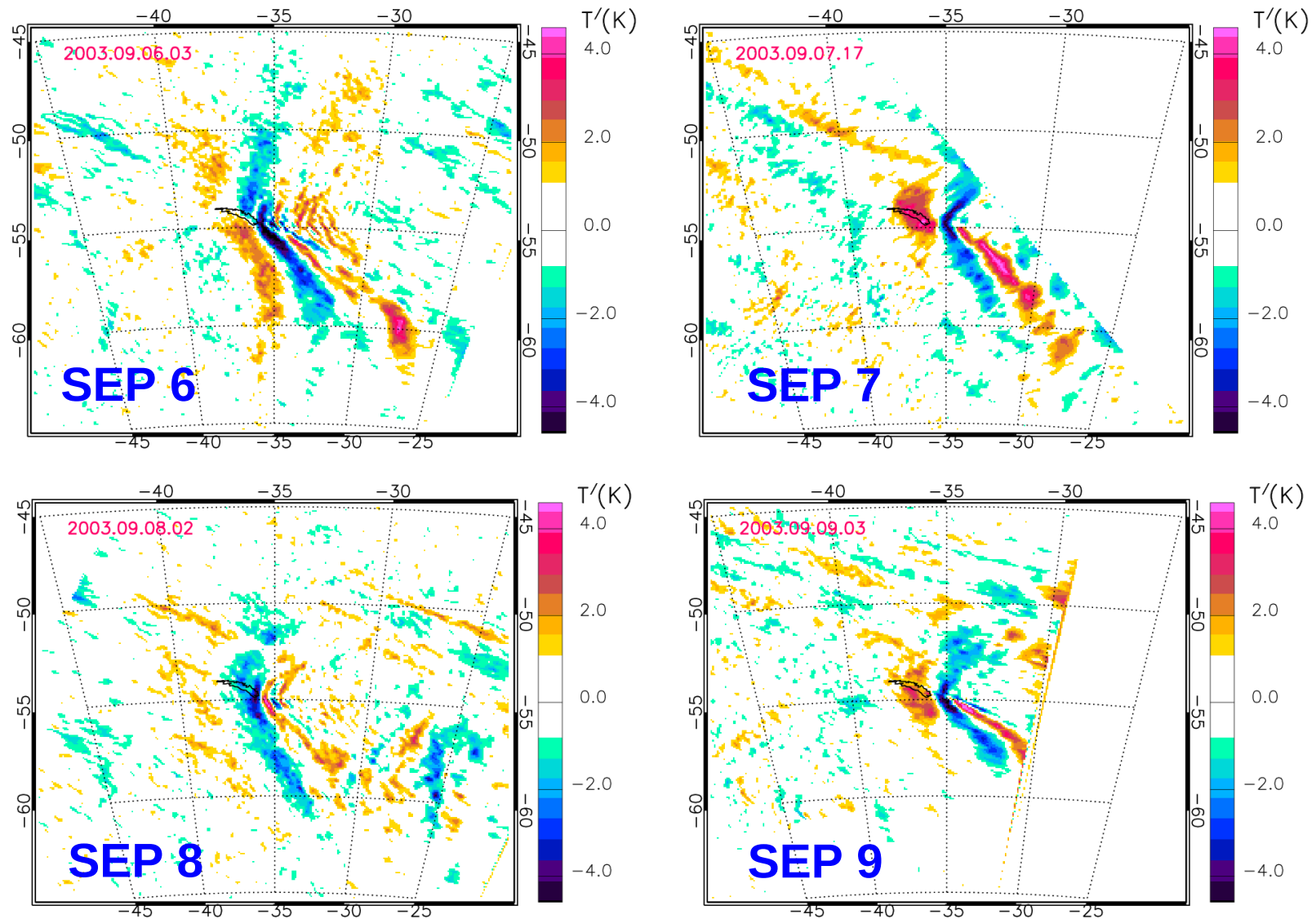
Vector Momentum Flux Estimated from AIRS Observations

Momentum Flux
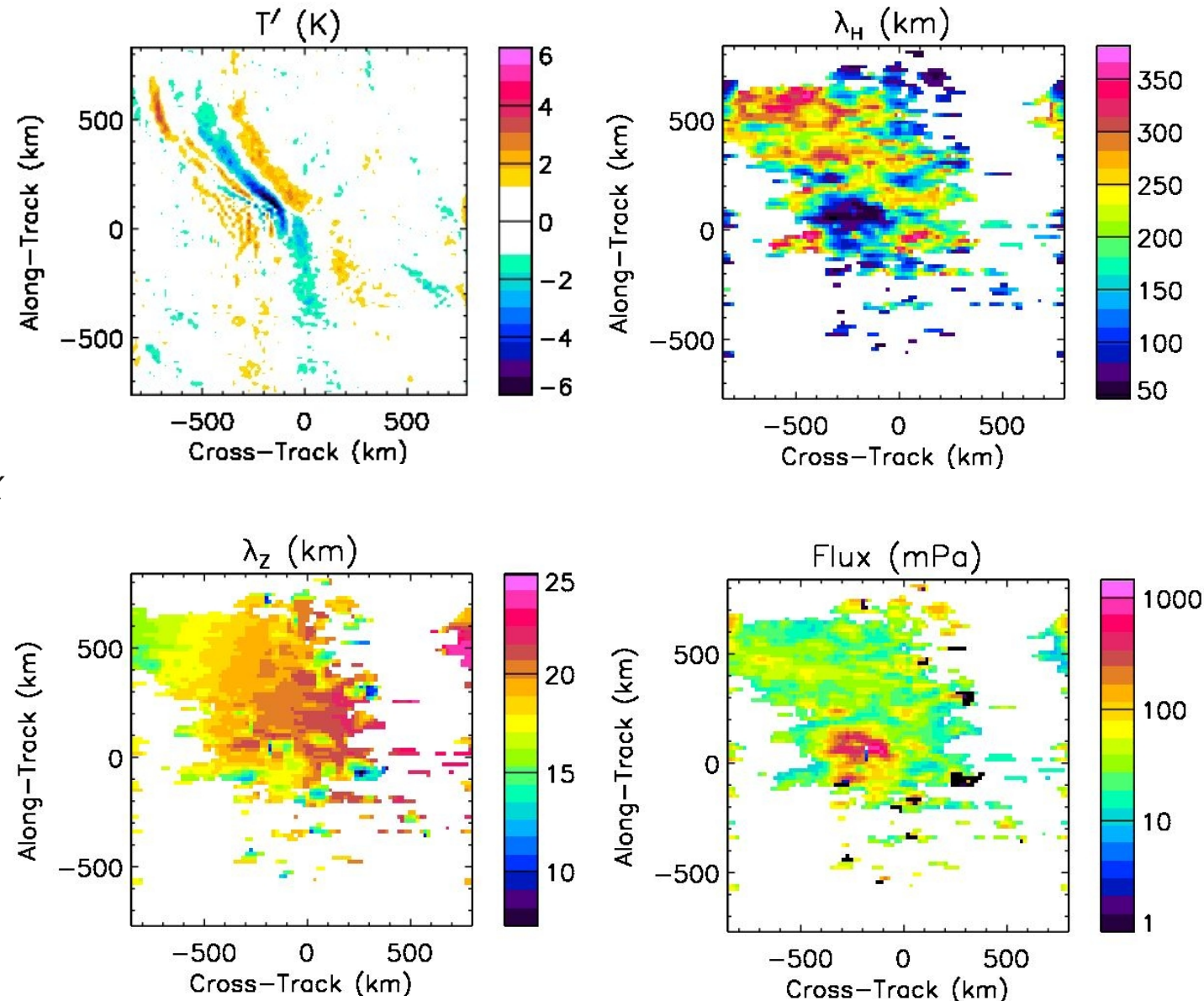$\sim (\lambda_Z/\lambda_X)(AT'/T)^2$
A=attenuation factor
(depends on λ_Z as in
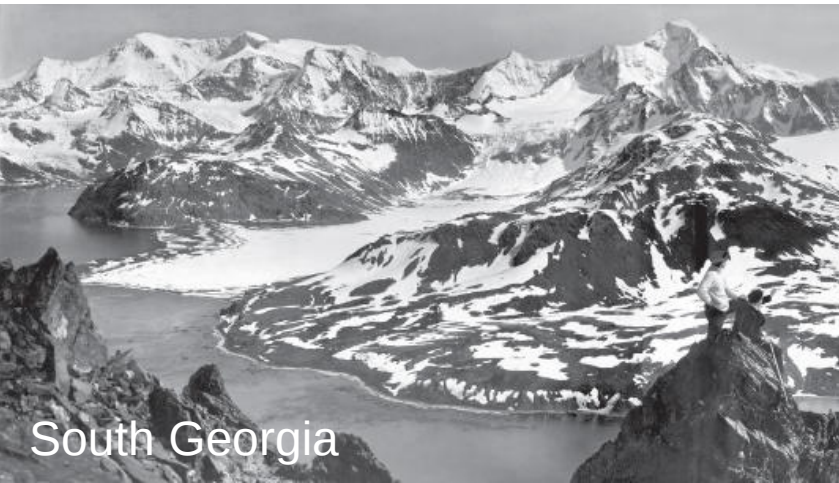Alexander & Barnet, 2007)

Wavelet analysis gives
horizontal wavelength λ_X
propagation direction.

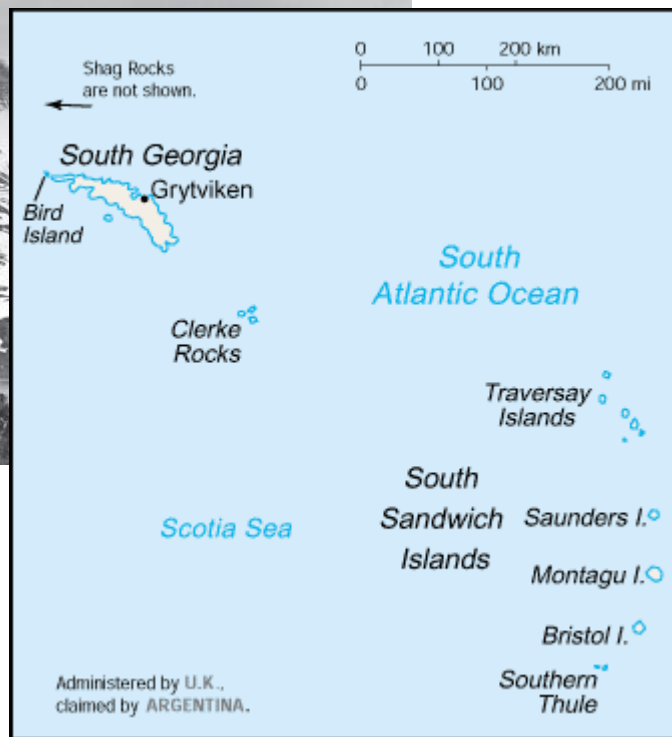Vertical wavelength λ_Z
from the gravity wave
dispersion relation,
$\quad \lambda_Z=2\pi(N^2/U^2-k^2)^{-1/2}$
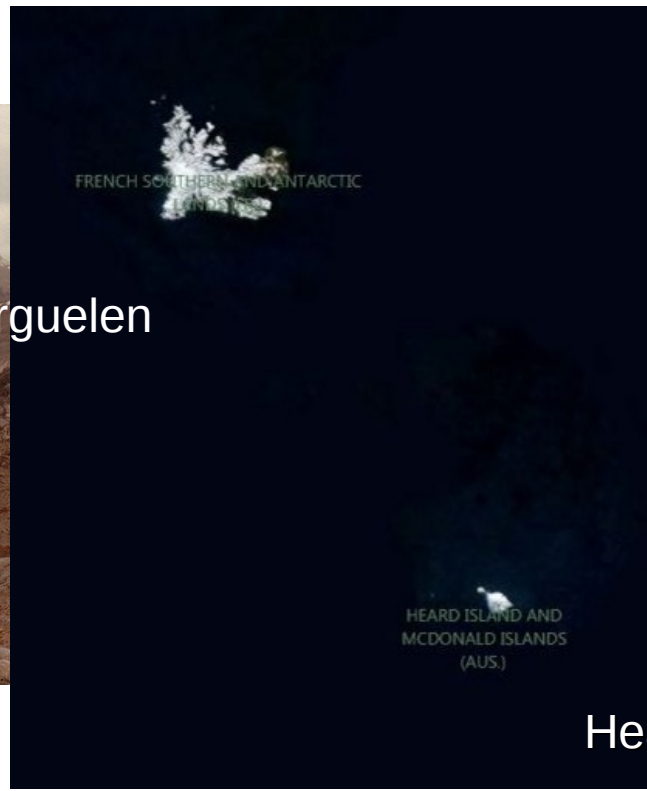N=buoyancy frequency
U=wind in propagation
$\quad$ direction.

South Georgia
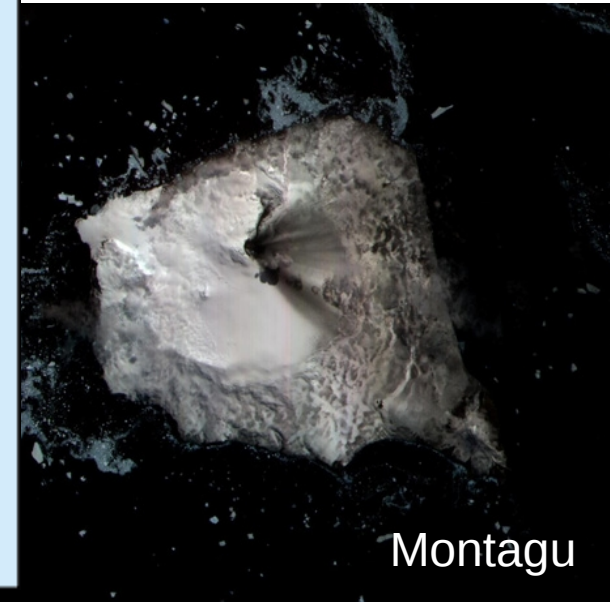
Montagu

South Georgia 2900 m
South Sandwich 1370 m
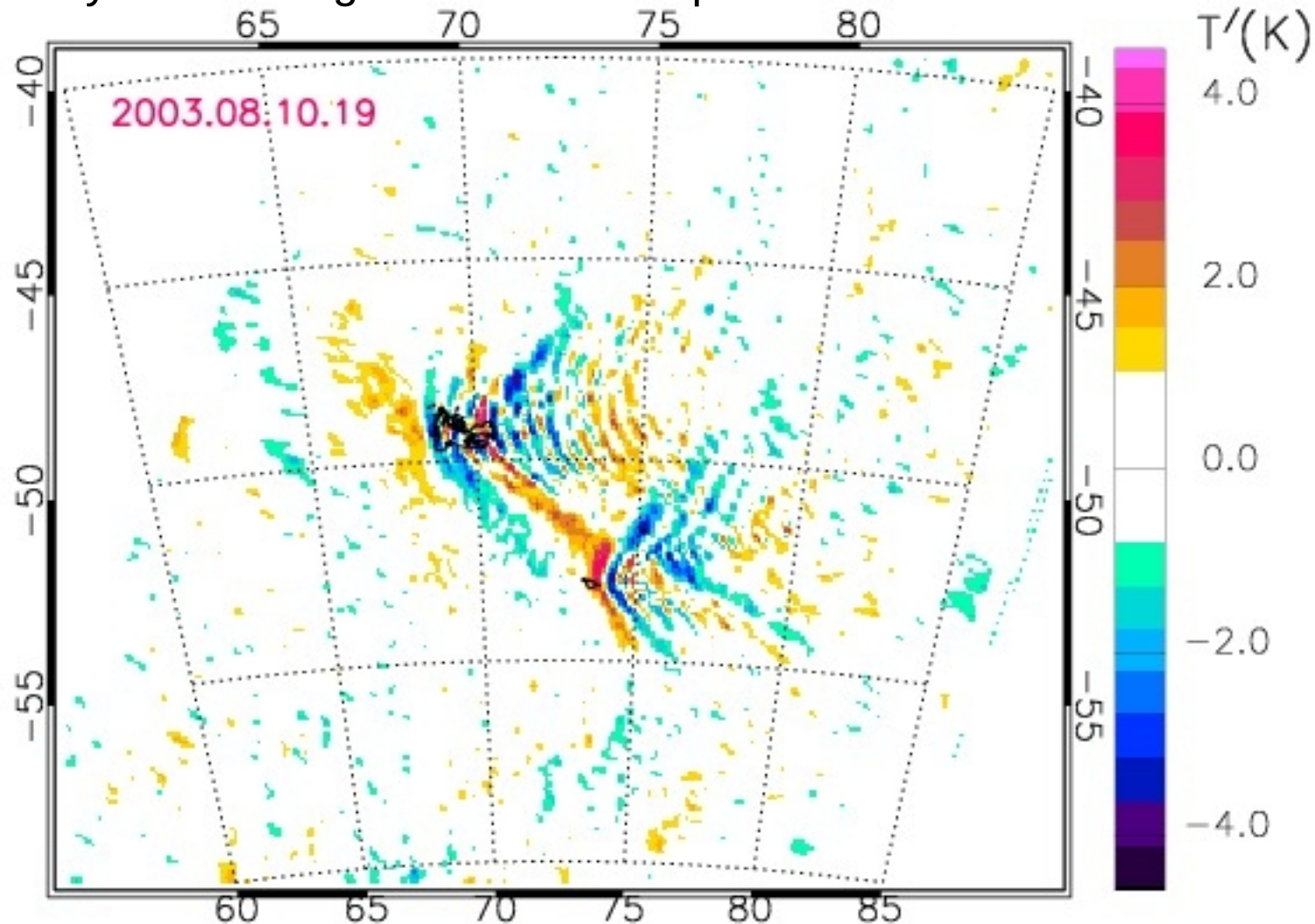Kerguelen 1,850 meters
Heard 2700 m

Kerguelen

Heard

Island Gravity Waves in AIRS

Heard and Kerguelen Islands
• Similar features appear above other islands in the Southern Ocean
• We are quantifying the momentum flux from these island sources to quantify the missing southern hemisphere flux in climate simulations.

Island Gravity Waves in AIRS

July-August-September 2003-2004 Event-Average Fluxes
(preliminary results)

S. Georgia & Sandwich Is. (mPa)
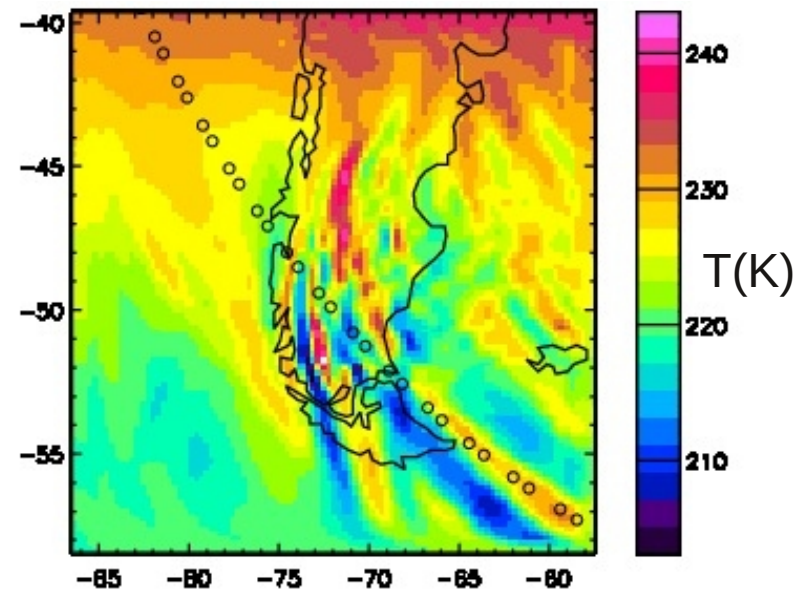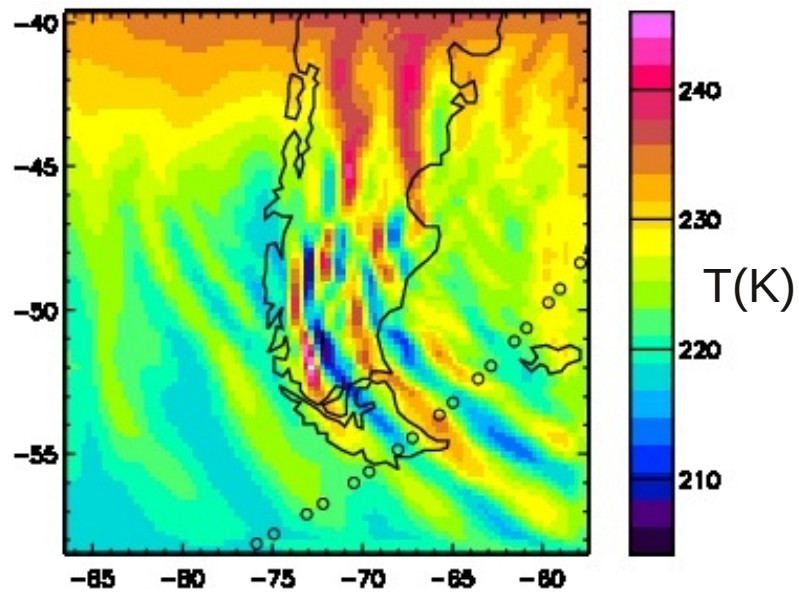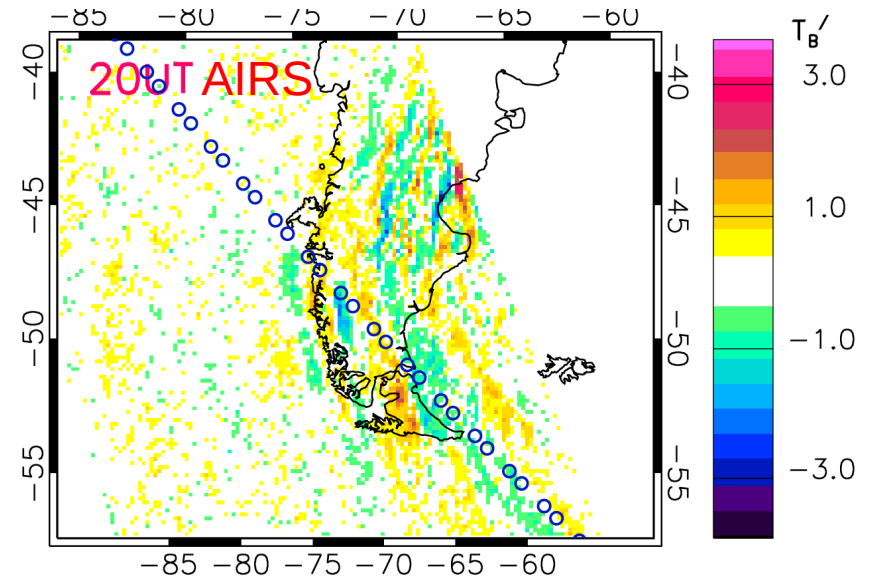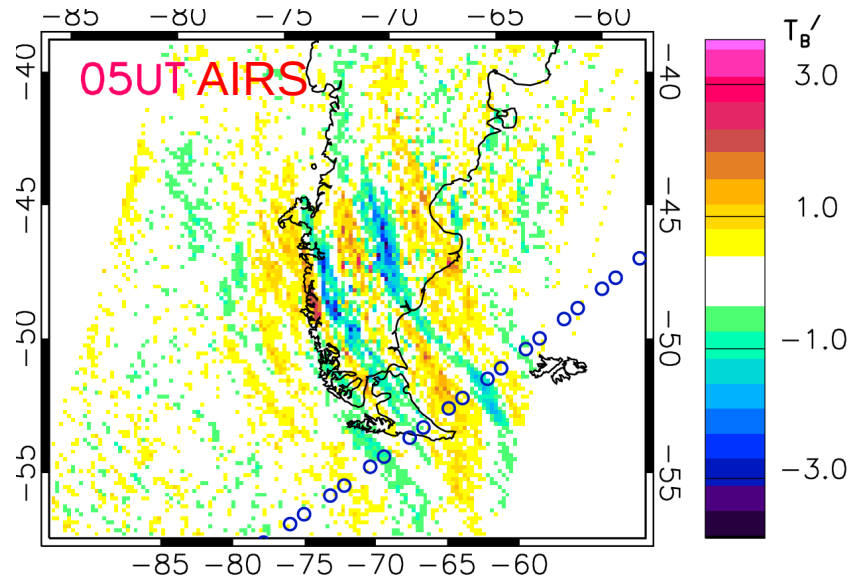
Heard & Kerguelen Is. (mPa)
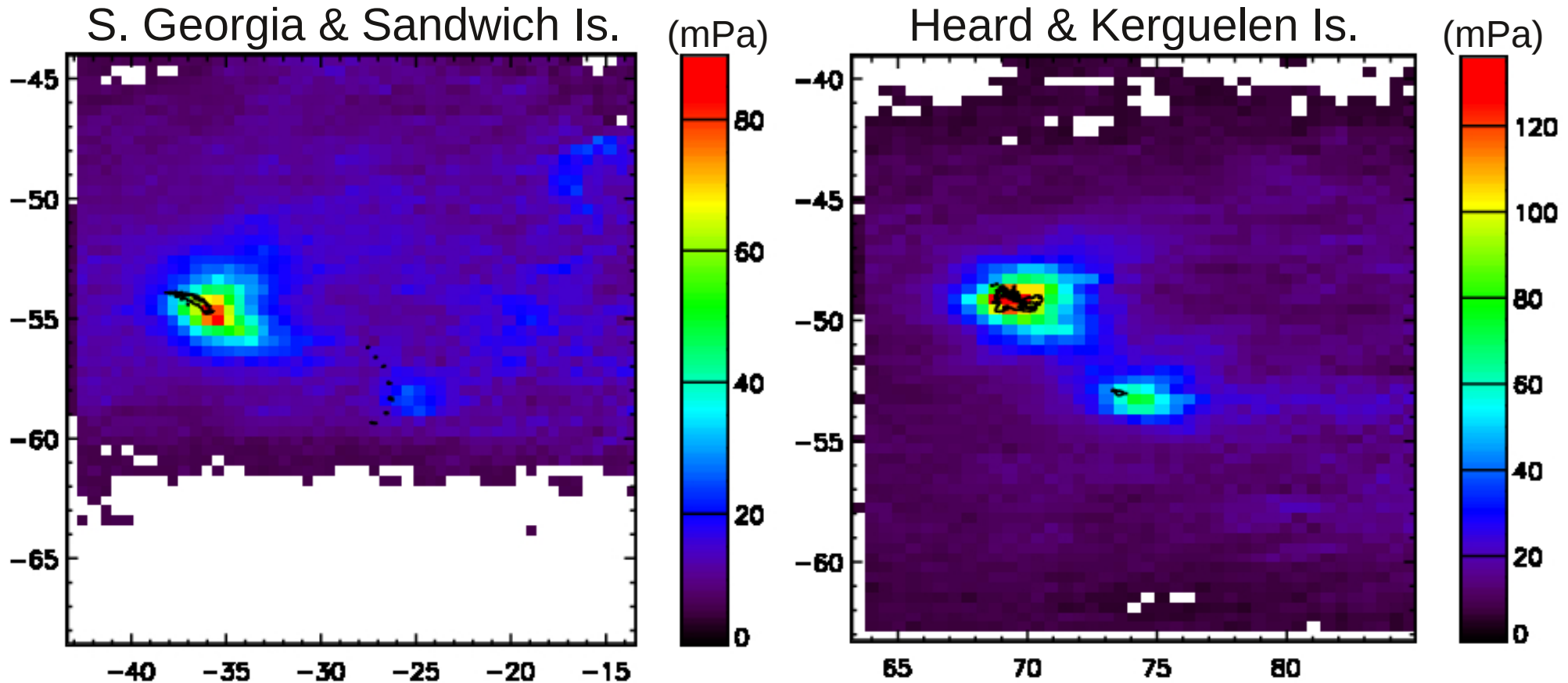
- 100 mPa momentum fluxes in the average are quite significant
- These events are common, ~50% of AIRS overpasses in Jul-Aug.
- Compare to zonal mean fluxes ~ 50 mPa in global model parameterizations at these latitudes [Webster et al., 2003]

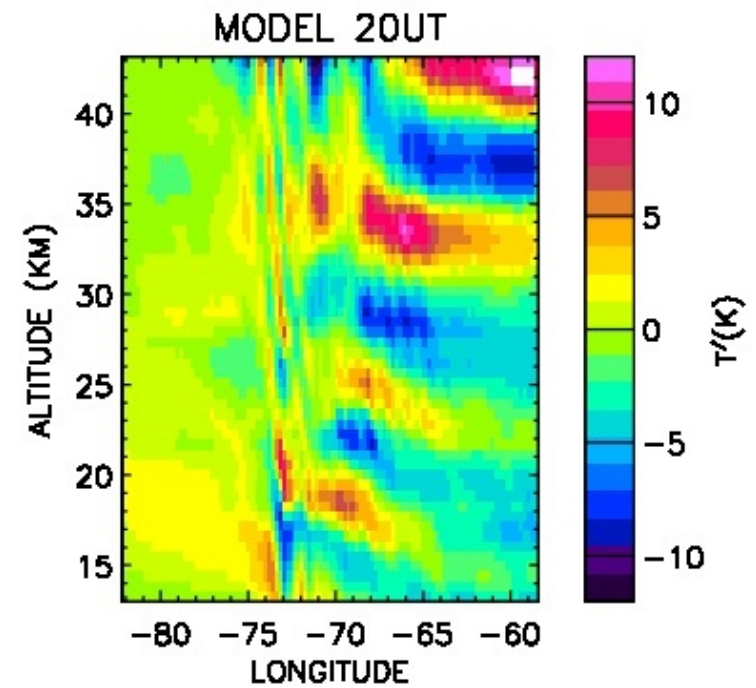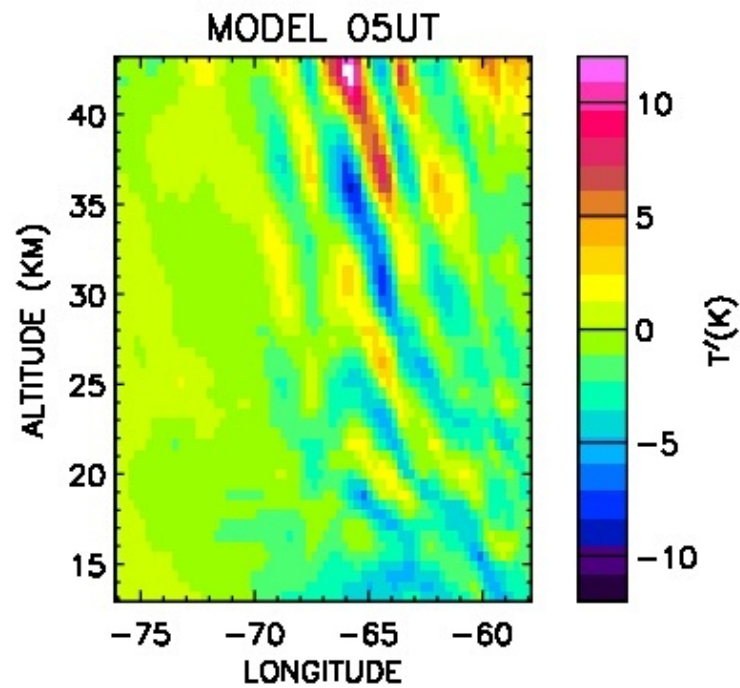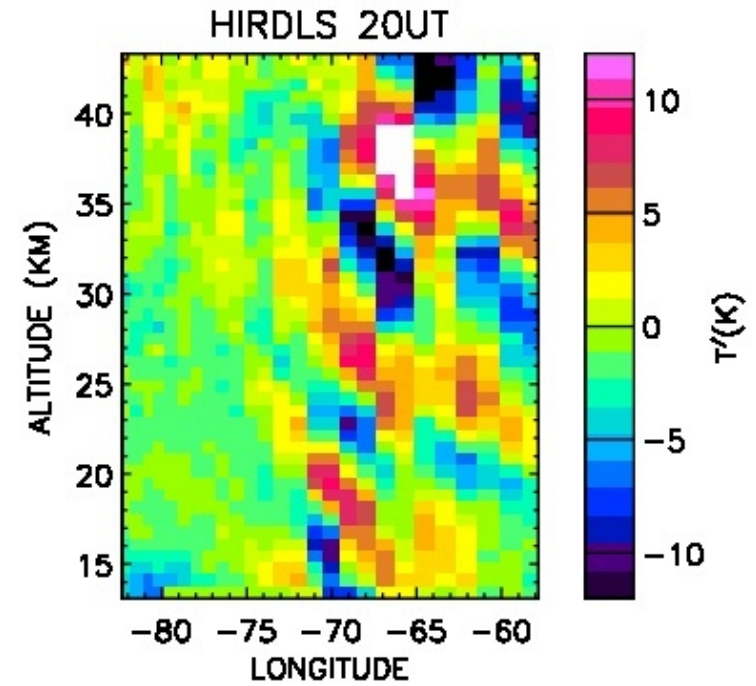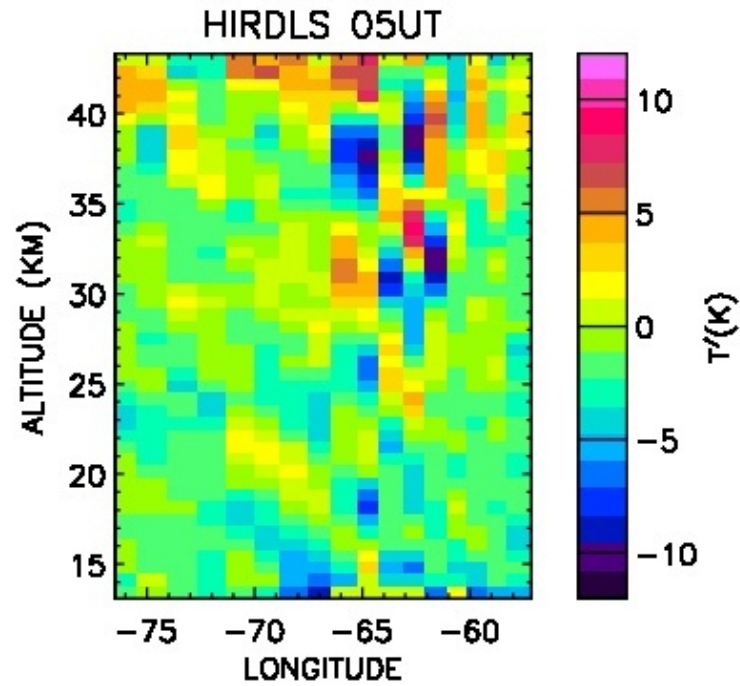# Southern Andes Mountain Wave Event – 8 May 2006
AIRS and HIRDLS
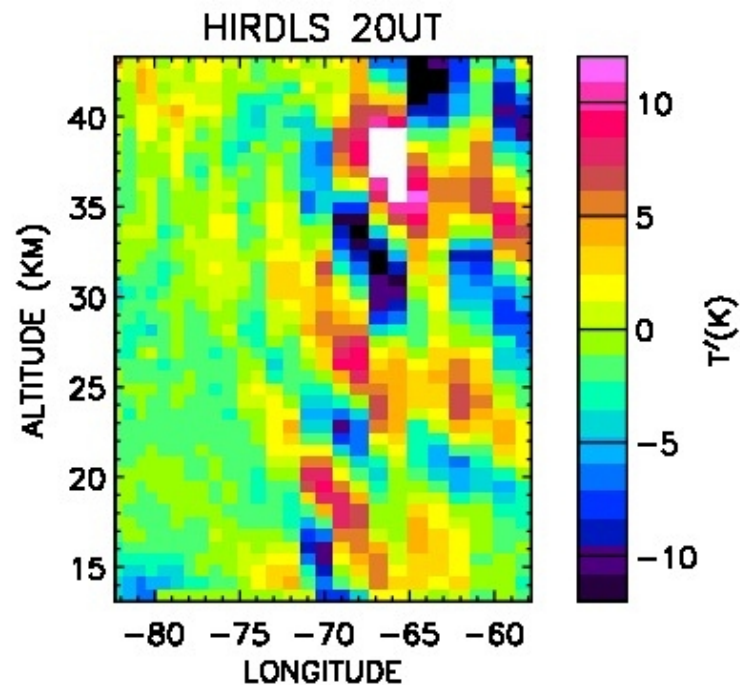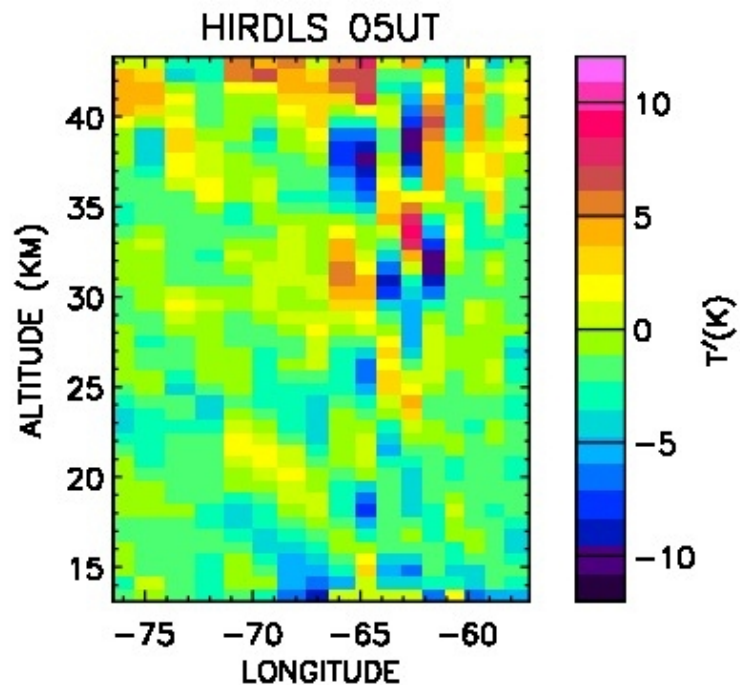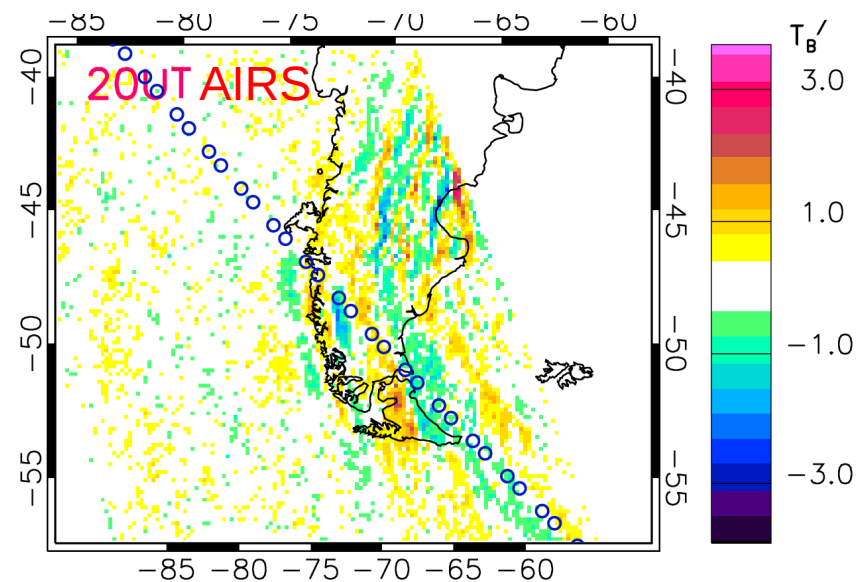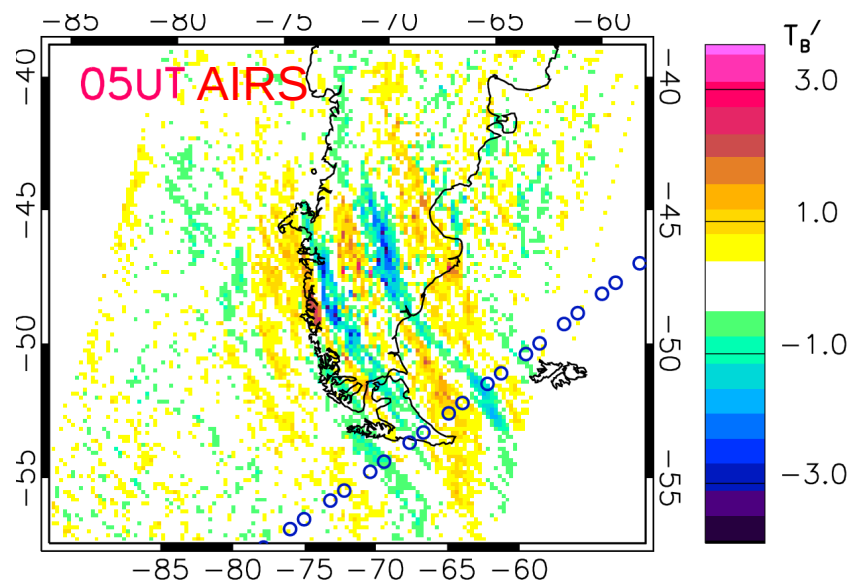
WRF Simulation Comparison to AIRS

WRF Simulation Comparison to HIRDLS

Analyzed Temperatures in ECMWF at 40 km Altitude

T (K) with HIRDLS track
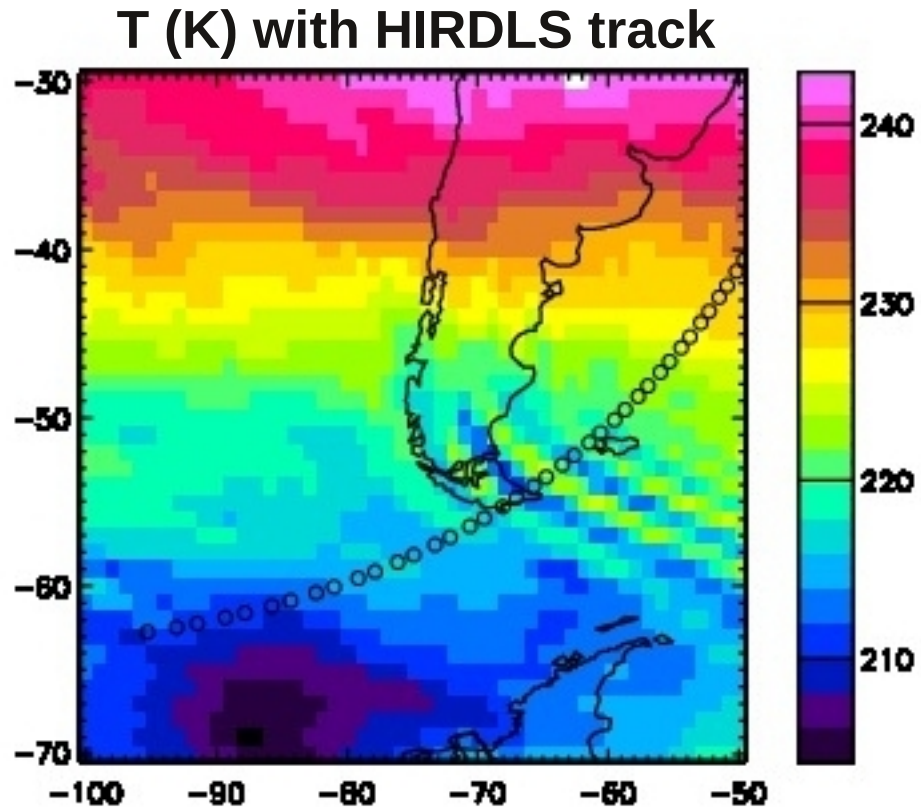
Similar pattern of waves extending to the south and east over the ocean.

Horizontal wavelength is ~400 km much longer than observed (~200km)

The waves are stationary and appear in both analysis and forecast fields.

Short horizontal wavelength waves observed directly above the mountains are absent in ECMWF.

Analyzed Temperatures in ECMWF - Cross-section

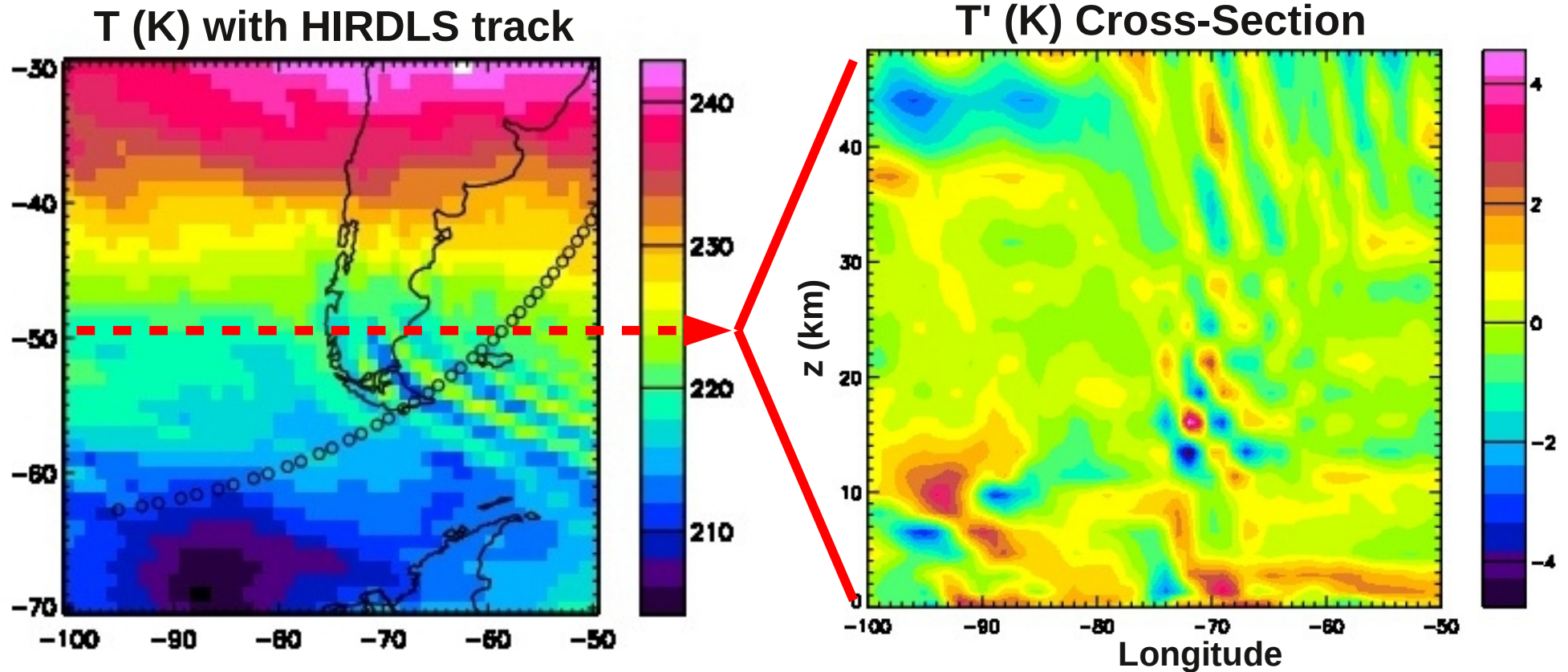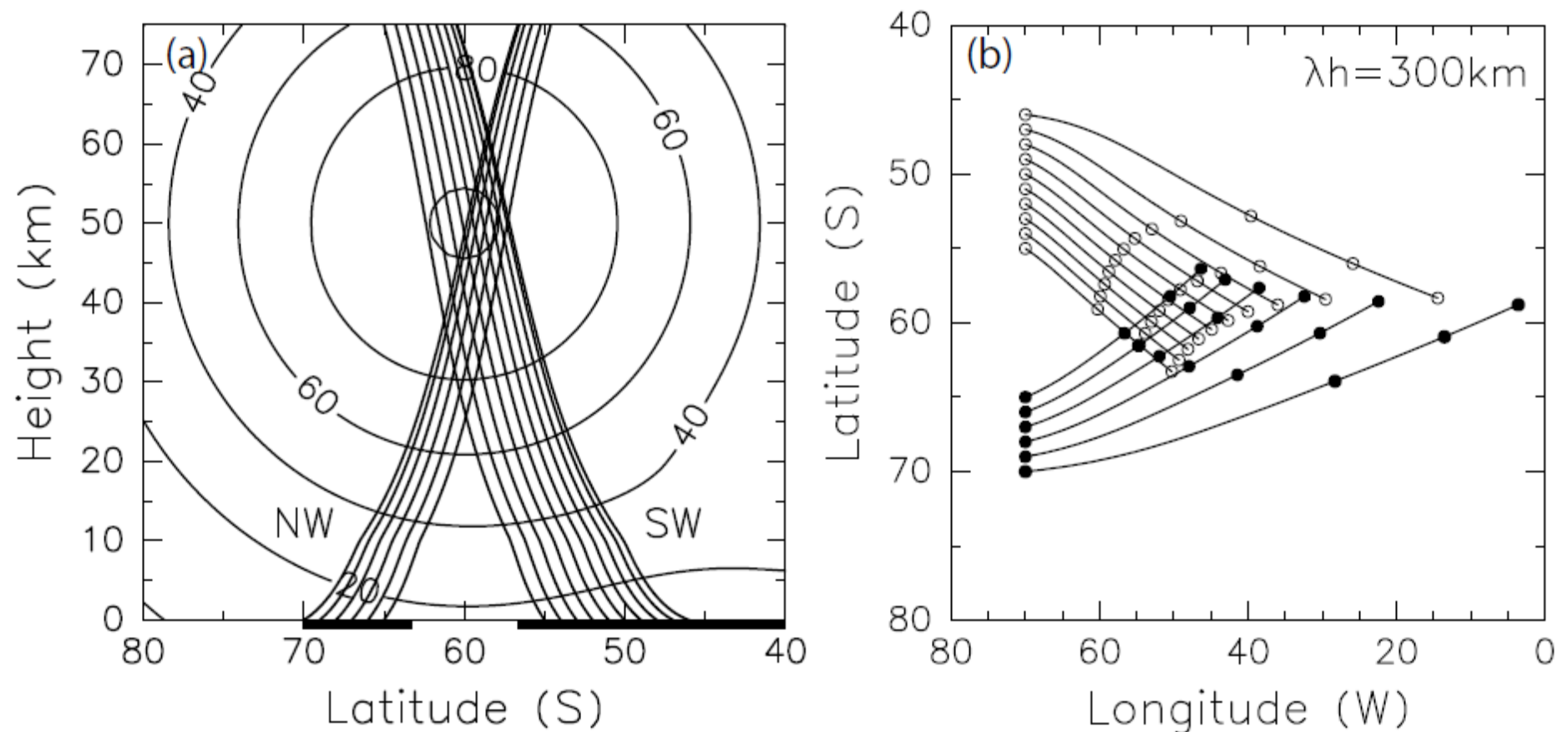**T (K) with HIRDLS track**

T' (K) Cross-Section

- Cross-Section: Waves originate near the surface above the topography.
- Although wavelength is long compared to the observations, it is fairly short compared with the ECMWF resolution (~40 km in 2006).

# Mechanism for Downstream Propagation of Mountain Waves

- Mechanism described in Sato et al. [2011] for downstream propagation into the jet core when a component of the group velocity is perpendicular to the wind.
- The effect is more pronounced for longer horizontal wavelength waves.
- Although phase is stationary, energy is advected downstream by the component of the wind perpendicular to the wavenumber vector.
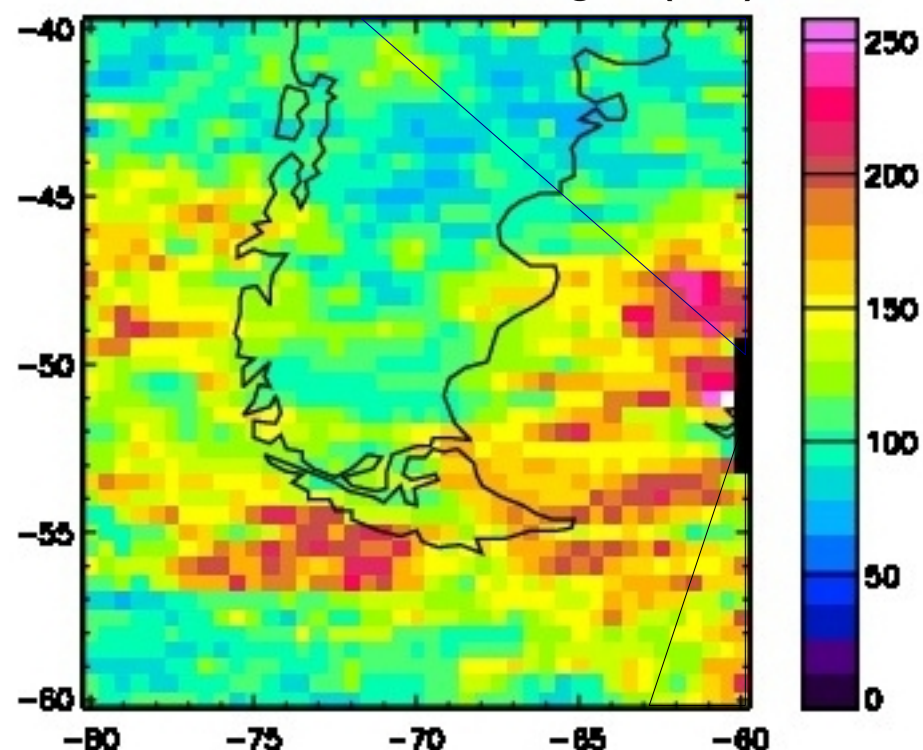
AIRS Day & Night Analyzed Wave Properties
May 8 Case

Momentum Flux (mPa)
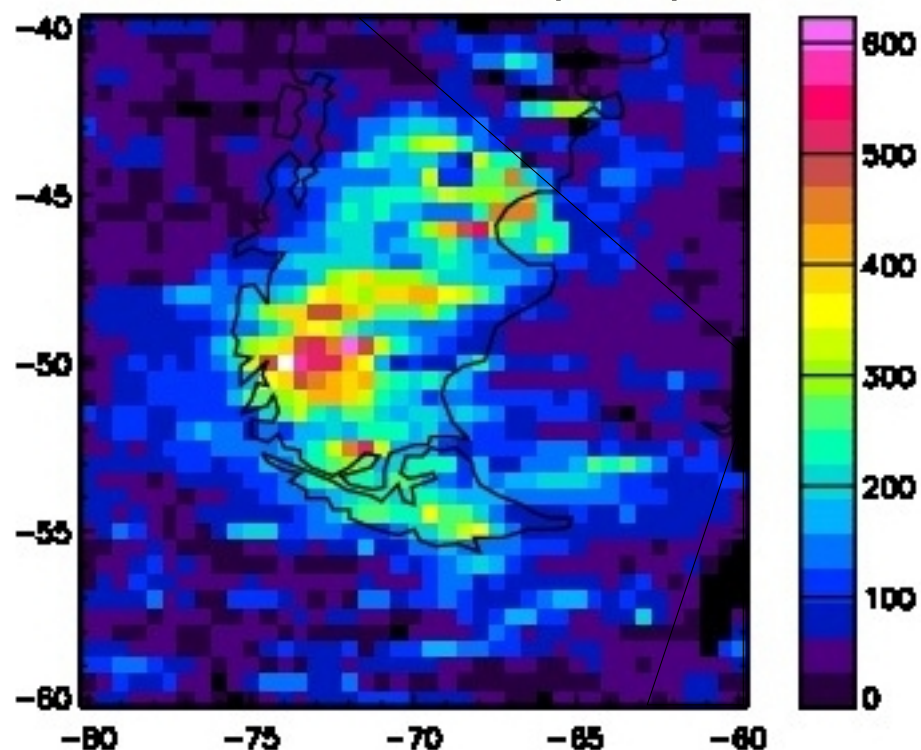
Horizontal Wavelength (km)

Region:	Avg. Flux	Vertical Wavelength	Horizontal Wavelength
75-71W, 52-48S	341 mPa	15.8 km	114 km
67-63W, 58-54S	103 mPa	14.8 km	156 km

Conclusions

- **Leeward energy propagation of Andes mountain waves also seen in AIRS observations and ECMWF analysis fields.**

  - These waves have longer horizontal wavelengths and much smaller momentum fluxes than the waves observed directly above the topography.

  - Orographic wave drag parameterizations are still needed to describe the smaller scale waves above the topography, and their propagation is more nearly 2-d, as assumed in the parameterizations.

- **AIRS reveals short mountain waves that have important circulation effects, but which remain unresolved in high-resolution global models.**